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Technology, Capabilities, and Performance of Low Power THz Sources

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WFC: Emerging Technology of Terahertz Imaging Systems, Devices, and Algorithms
Friday, June 22, 2012

Why Terahertz Science is Important

2 August 2011 Last updated at 10:53 ET

Oxygen finally spotted in space

"Hidden" oxygen may be released from dust grains and ice in star-forming regions

One of astronomy's longest-running "missing persons" investigations has concluded: astronomers have found molecular oxygen in space.

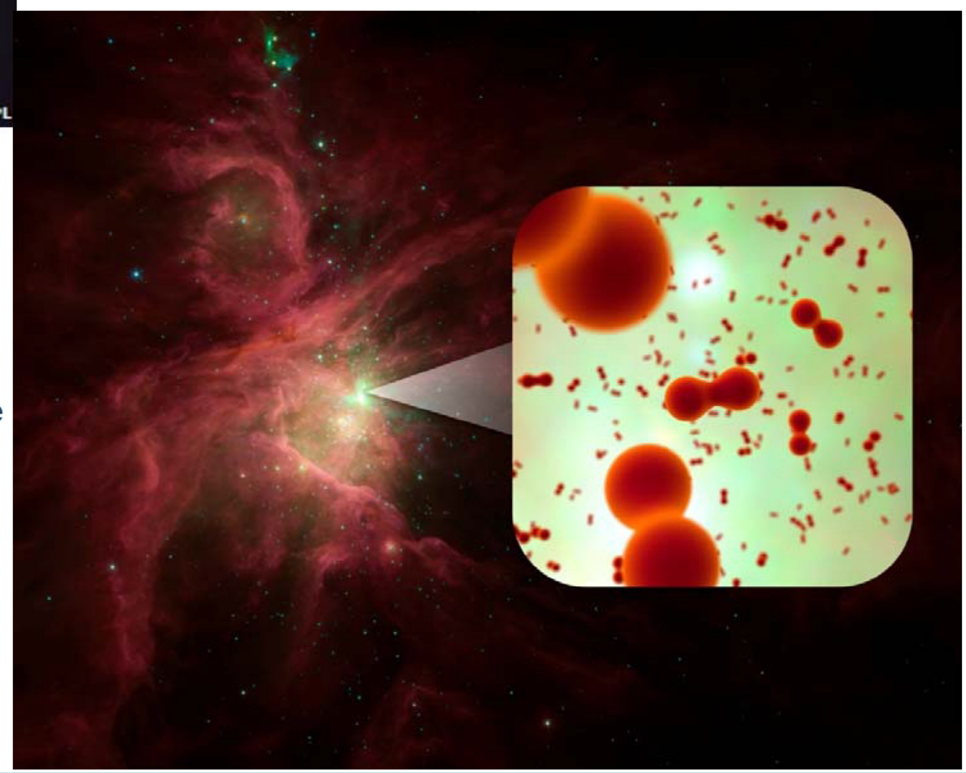
While single atoms of oxygen have been found alone or incorporated into other molecules, the oxygen molecule - the one we breathe - had never been seen.

The Herschel space telescope spotted the molecules in a star-forming region in the constellation of Orion.

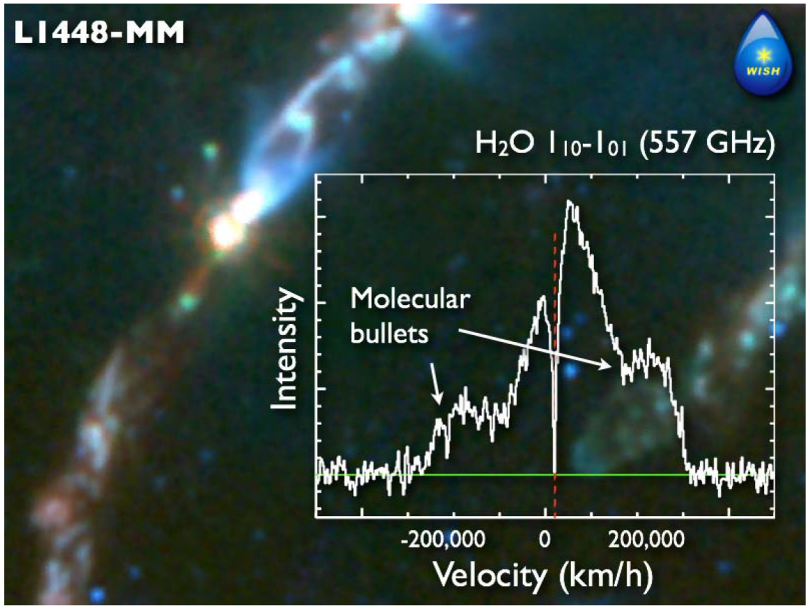
The find **will be published in the Astrophysical Journal**.

Ref: Paul Goldsmith et. al.,

Herschel Space Observatory's HIFI Instrument



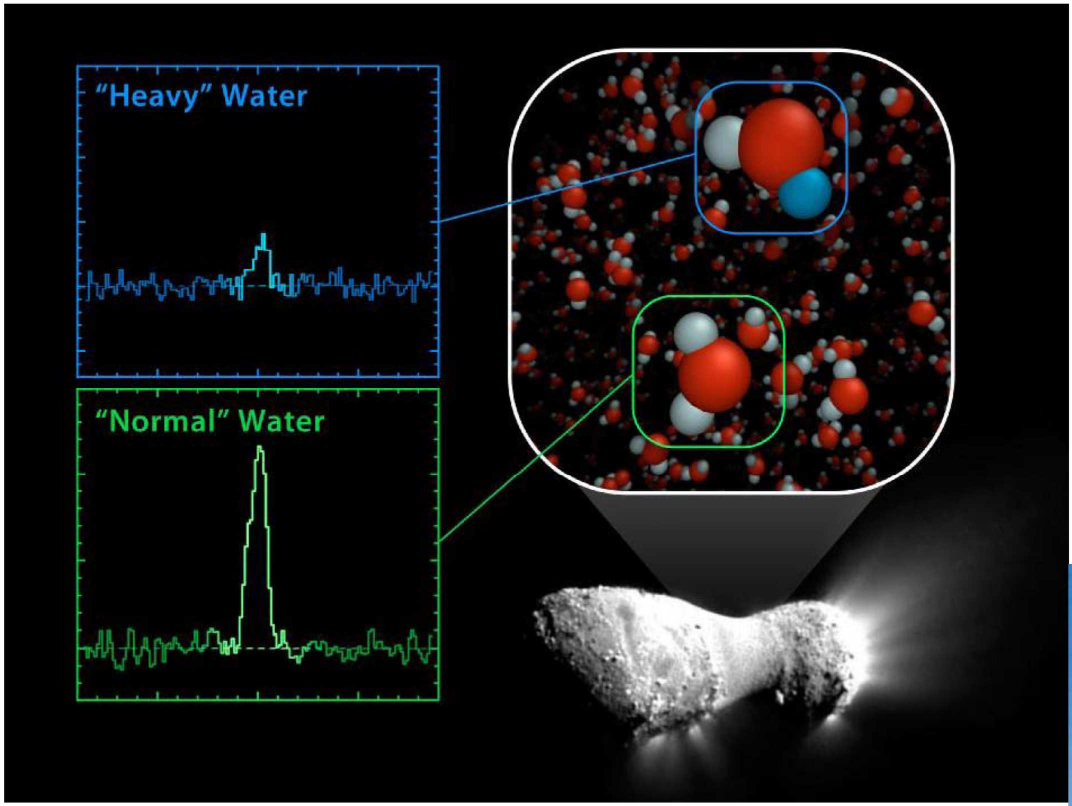
Why Terahertz Science is Important



Observations with Herschel-HIFI of water in a young Sun-like star reveal high-velocity "bullets" moving at more than 200,000 km/h from the star. This can be compared to the velocity of a bullet from an AK47 rifle, which is 2500 km/h or 80 times slower. It is a surprise that water molecules are observed at this high velocity - they should have been destroyed in the shock where temperatures exceed 100,000 degrees.

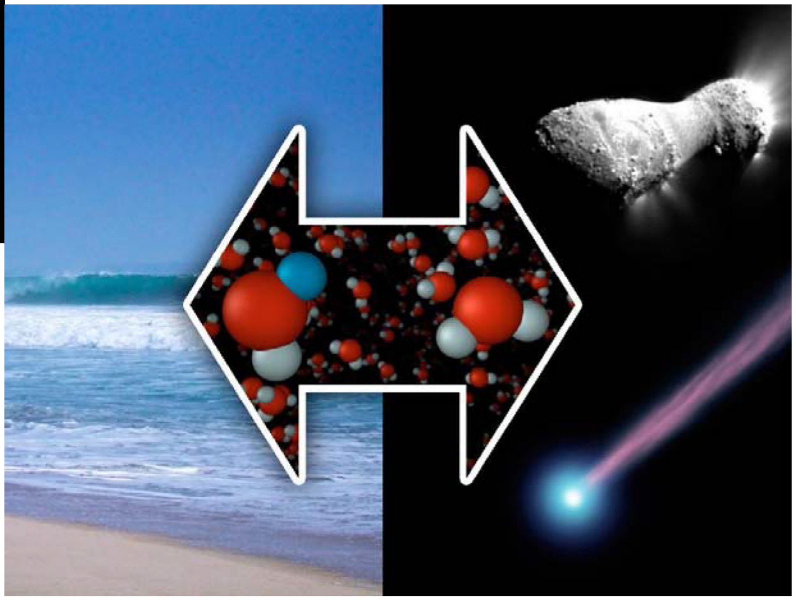
Therefore the observations reveal that water very likely reforms rapidly in the hot and dense shocked gas. The conditions are so favorable that approximately 100 million times the amount of water in the Amazon river is formed, every second!

Why Terahertz Science is Important



Herschel Space Observatory’s HIFI Instrument (JPL).

“Earth’s water may have come from comets!”



LETTER   Nature, October 2011

doi:10.1038/nature10519

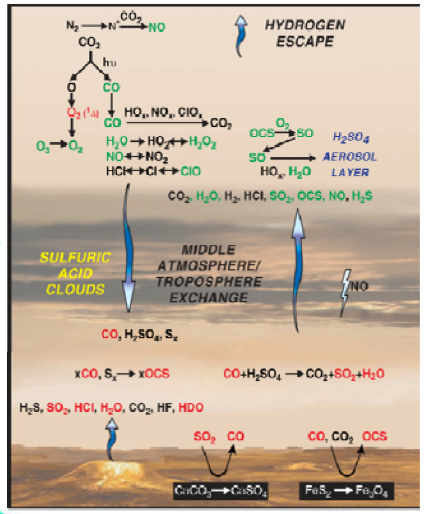
Ocean-like water in the Jupiter-family comet 103P/Hartley 2

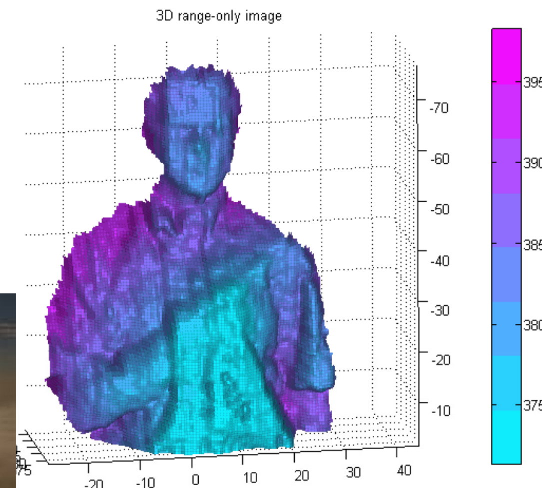
Paul Hartogh[1], Dariusz C. Lis[2], Dominique Bockelée-Morvan[3], Miguel de Val-Borro[1], Nicolas Biver[3], Michael Küppers[4], Martin Emprechtinger[2], Edwin A. Bergin[5], Jacques Crovisier[3], Miriam Rengel[1], Raphael Moreno[3], Slawomira Szutowicz[6] & Geoffrey A. Blake[2]

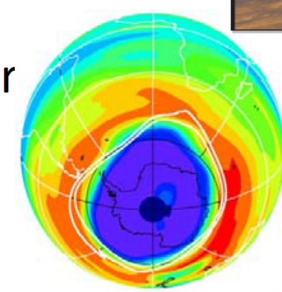
Technology Driven by Applications

Radiation in these wavelengths highlights:

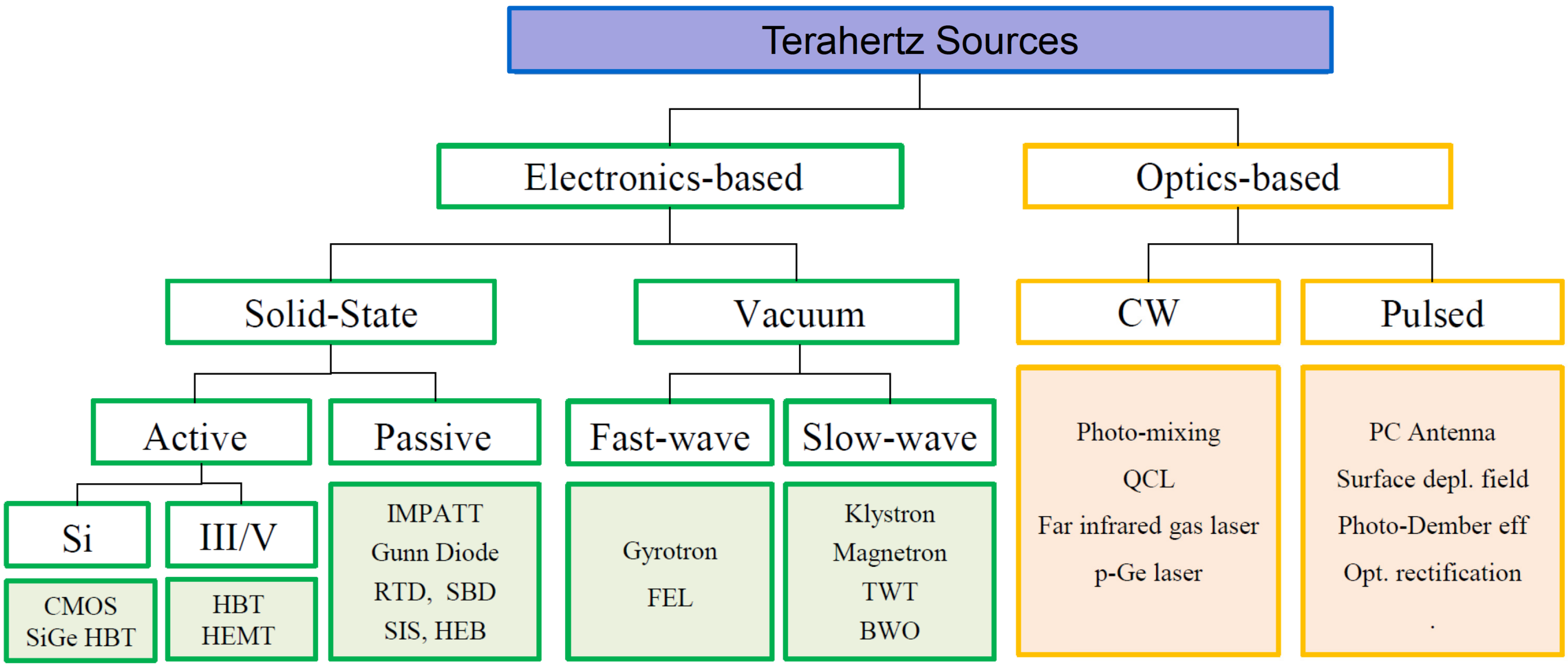
- Star and Galaxy Formation
- Dust and Gas Chemistry
- Cosmology and CMB Astrophysics
- Atmospheric Constituents and Planet Dynamics
- Global Atmospheric Monitoring
- Security Applications
- Wireless Power Transfer



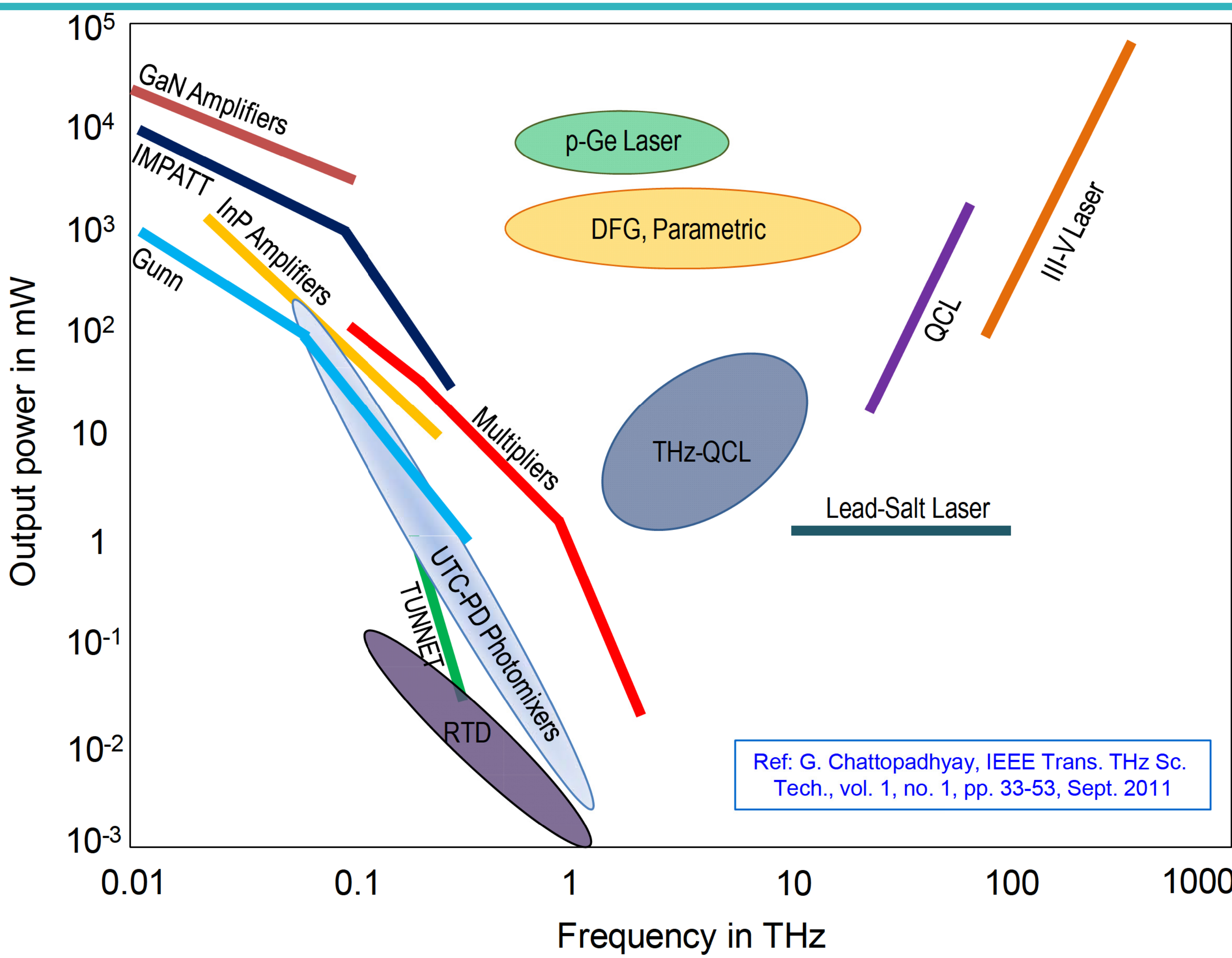




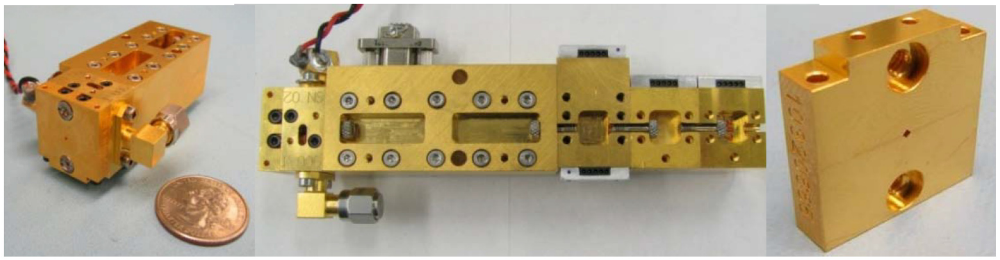
Terahertz Source Classifications

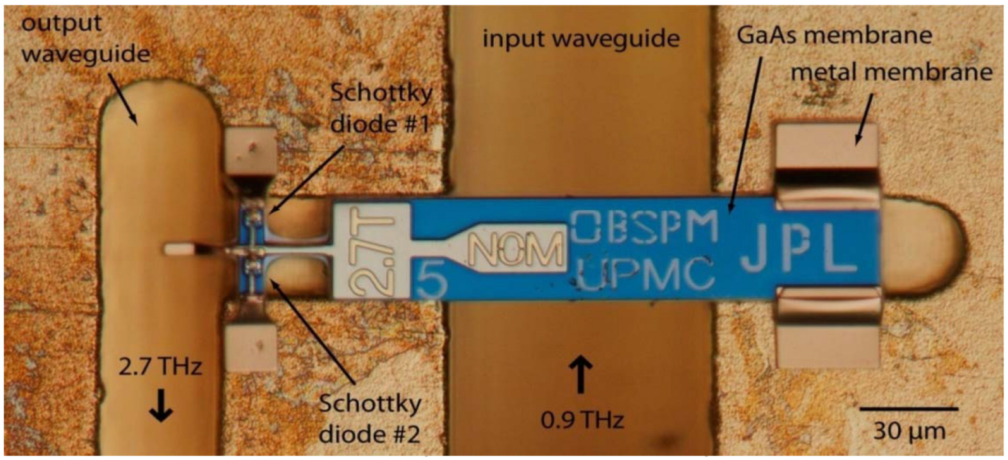


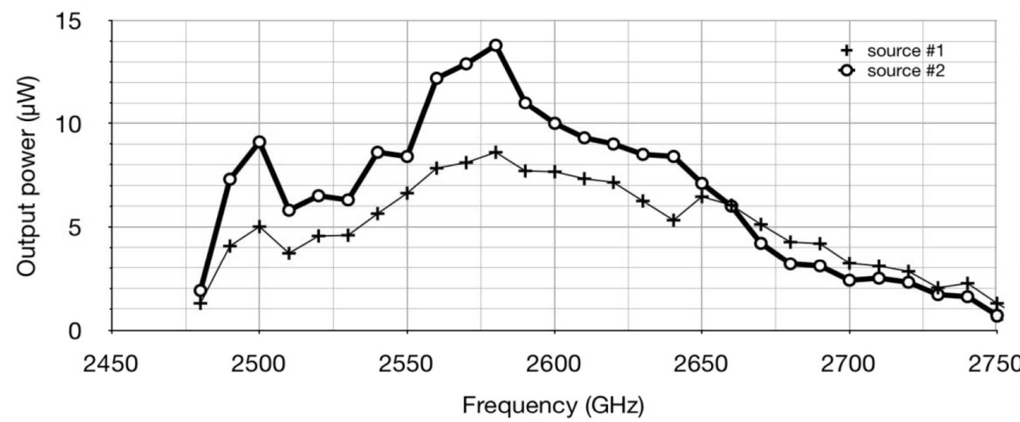
Terahertz Sources: Current Status

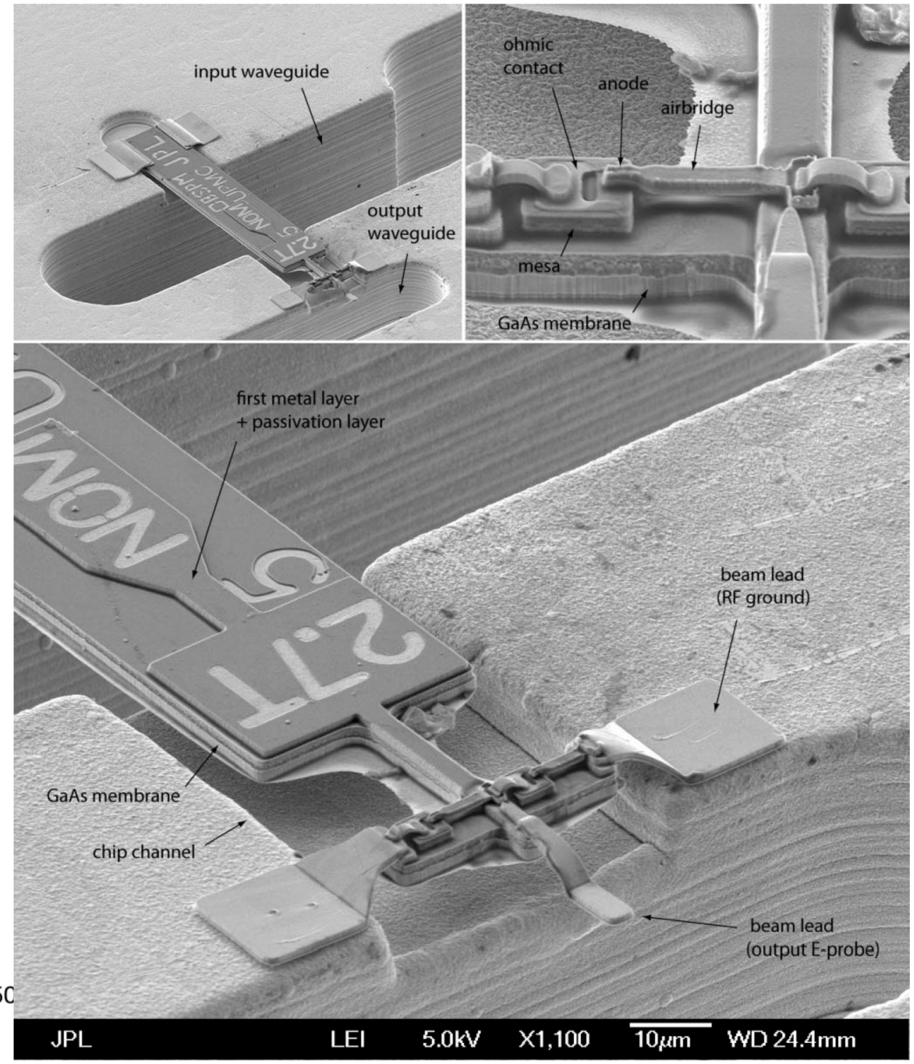


2.7 THz Solid-State Source

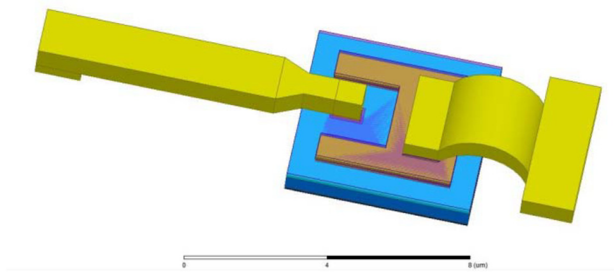






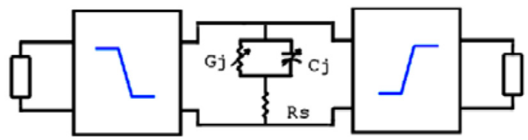


Schottky Diode Multipliers



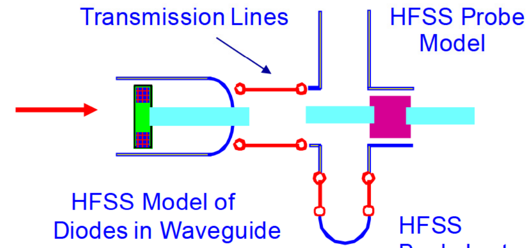
Planar Schottky Diode

1. Optimize Diode

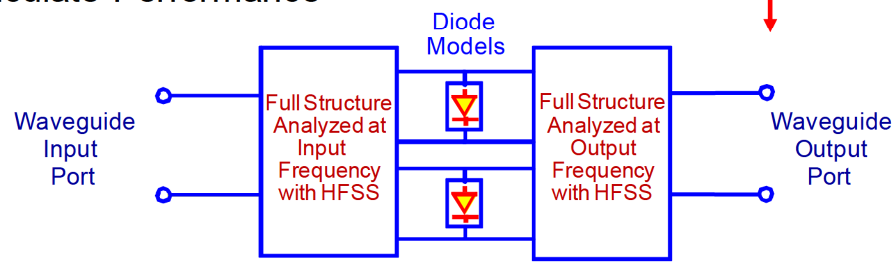


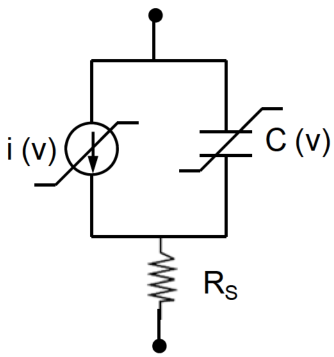
Optimize diode size and find embedding impedances using harmonic balance simulator and diode model

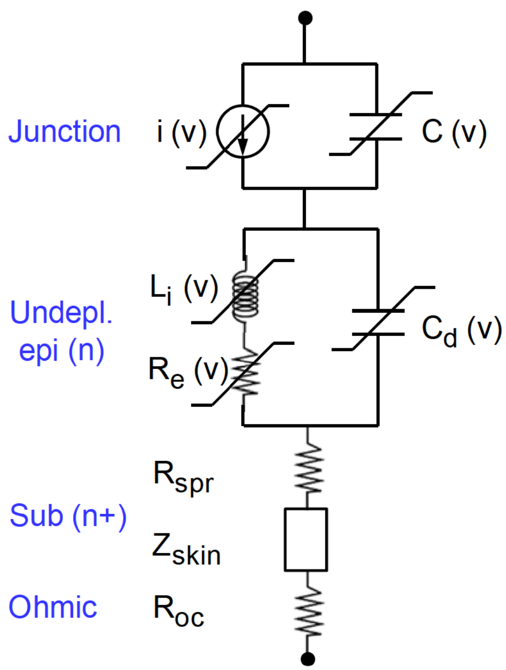
2. Design Linear Circuit

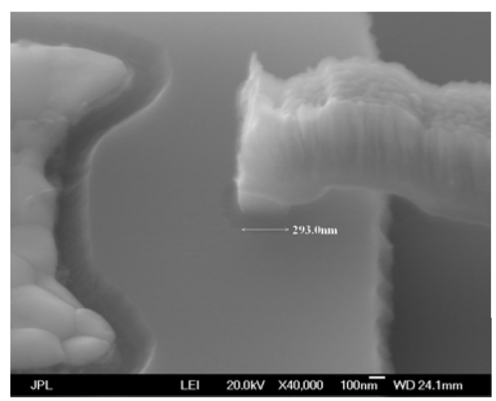


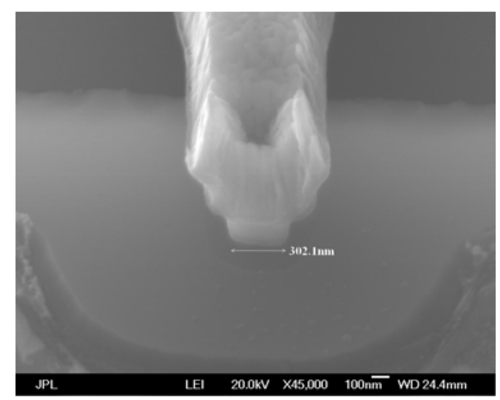
3. Calculate Performance





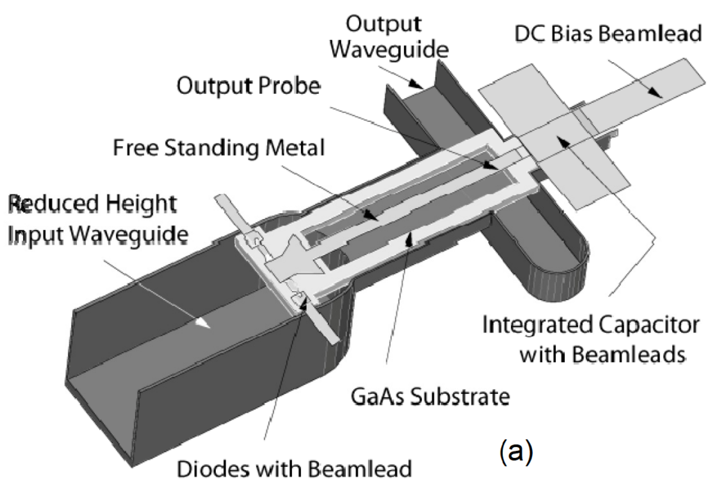


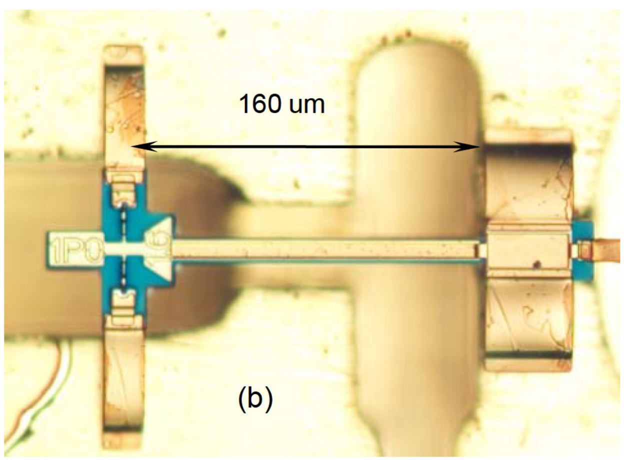




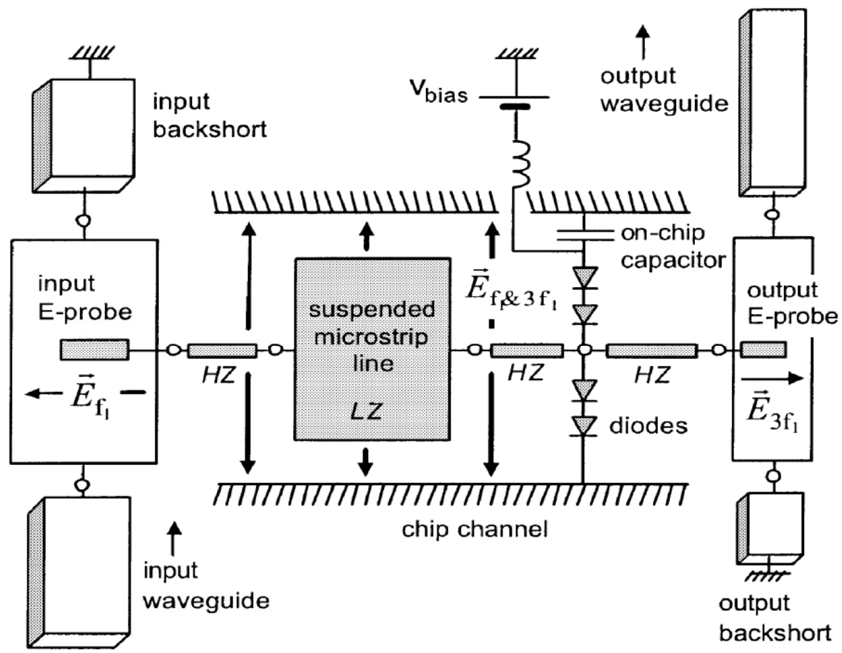
Frequency Multiplier Based Sources

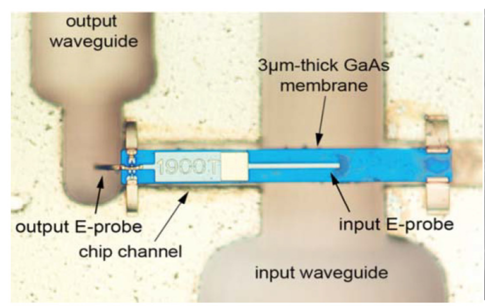
Frequency Doubler

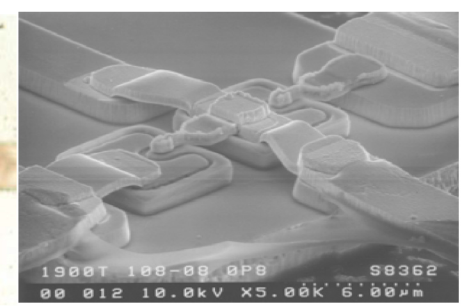




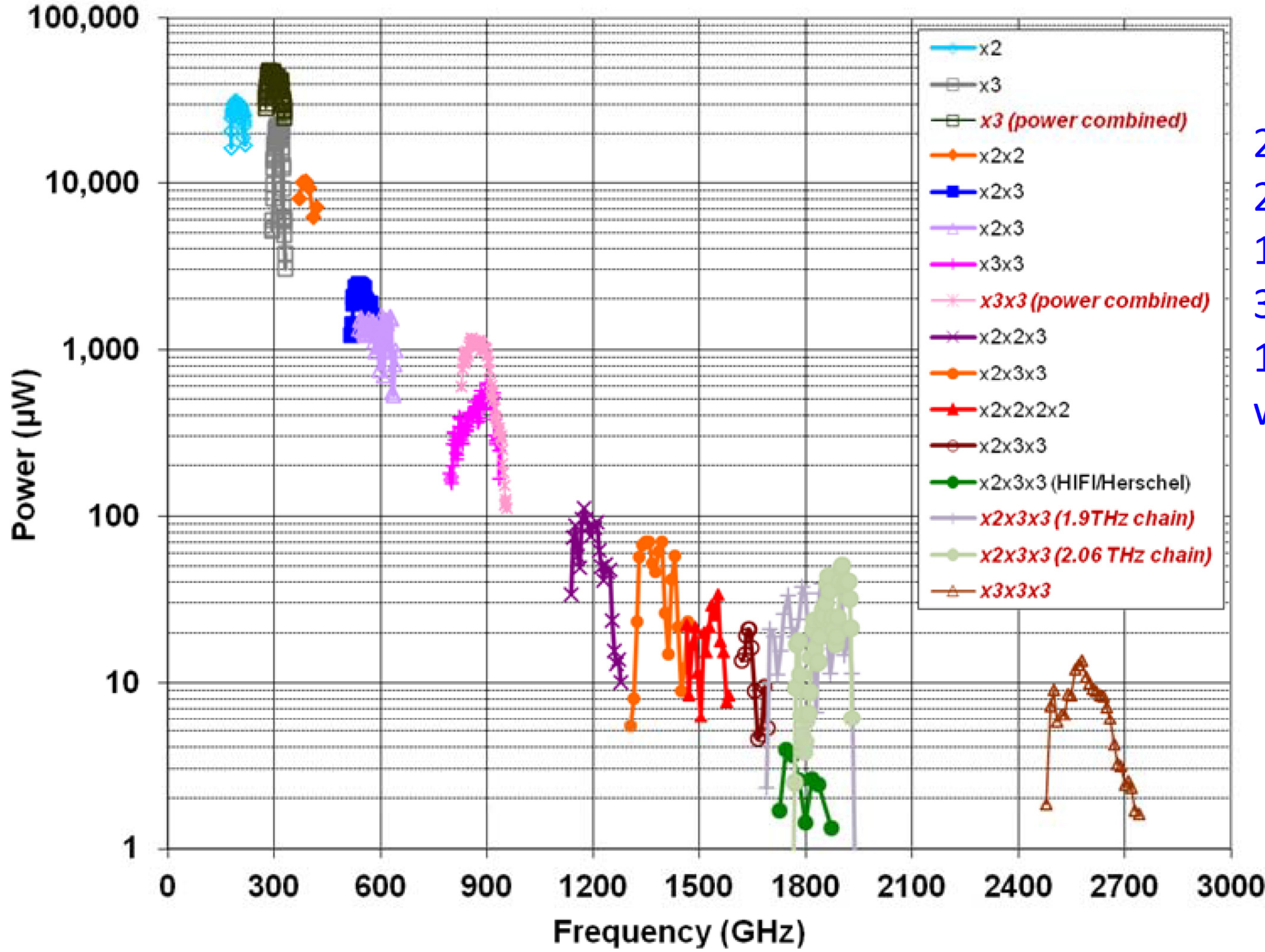
Frequency Tripler





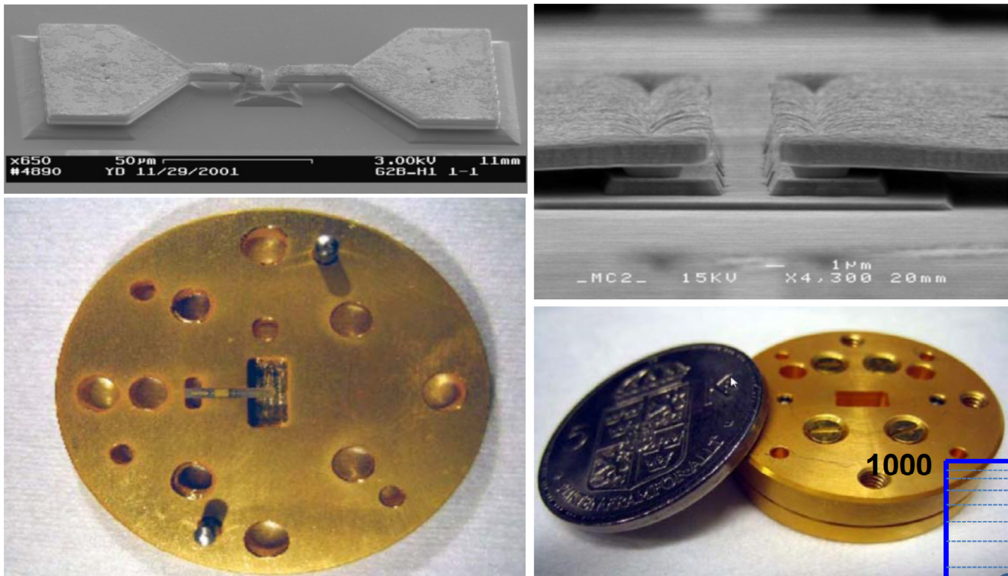


Frequency Multipliers: Current Status



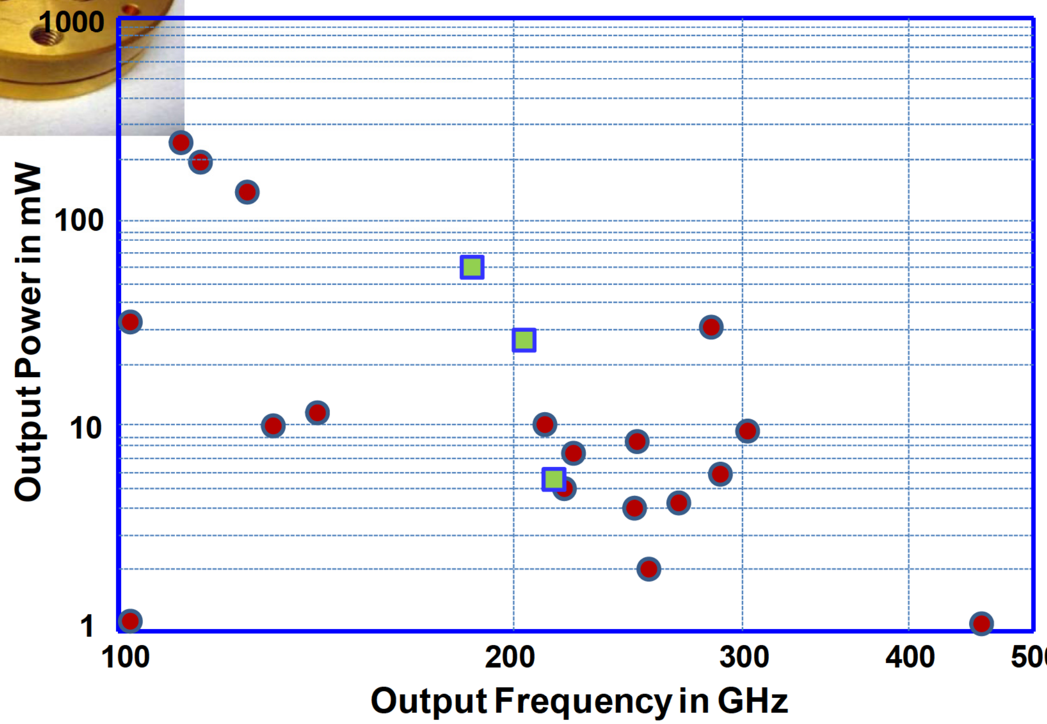
25% efficieny at 200 GHz
20% efficiency at 400 GHz
10% efficiency at 800 GHz
3% efficiency at 1600 GHz
1% efficiency at 2700 GHz
with more than 10% BW.

Frequency Multiplier Based Sources

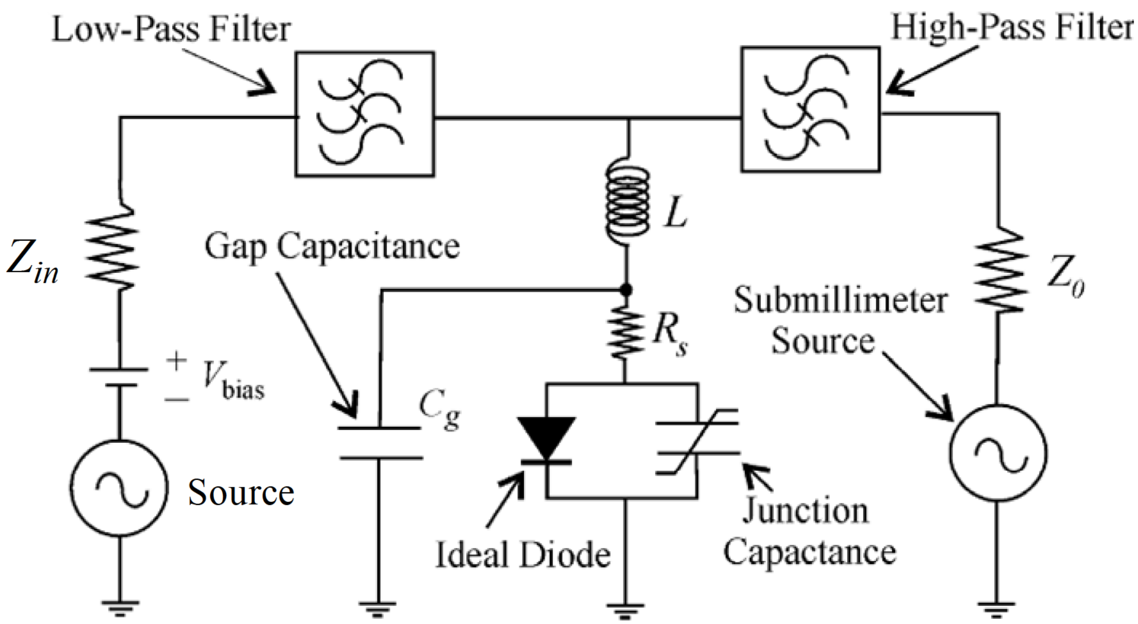


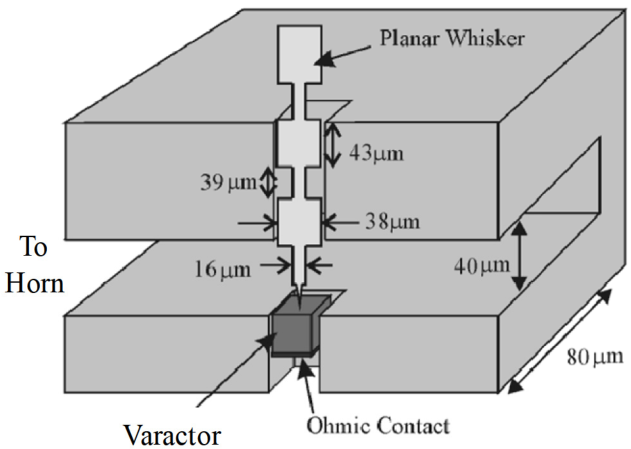
Heterostructure Barrier Varactor (HBV) Diode Based Frequency Multipliers

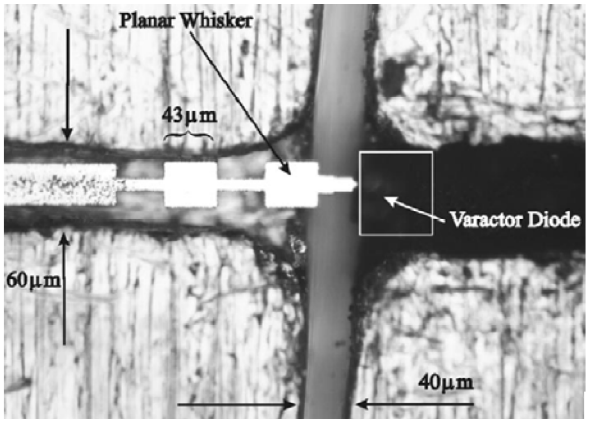
- Only odd frequency multiplication
- Capable of producing higher power
- Lower efficiency
- Maximum frequency (450 GHz)



Sideband Generators







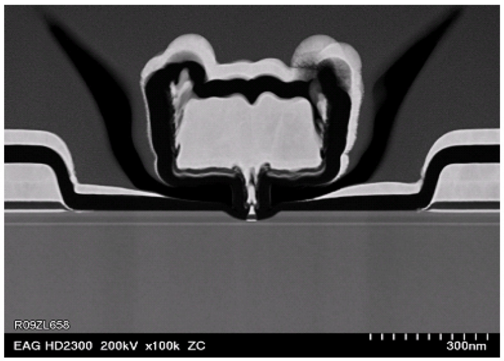
Sideband generators are similar to frequency multipliers: they use a nonlinear device to generate a high frequency signal by frequency upconversion.

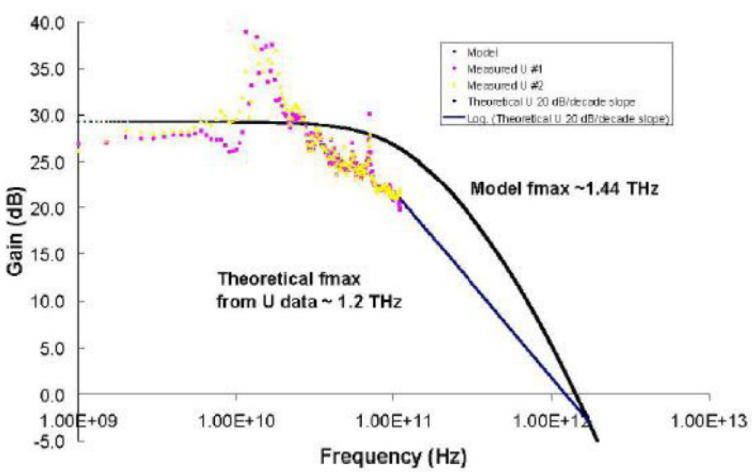
Efficiency is poor

Transistor Based Sources

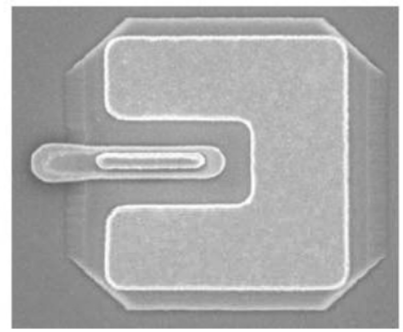
III-V technologies

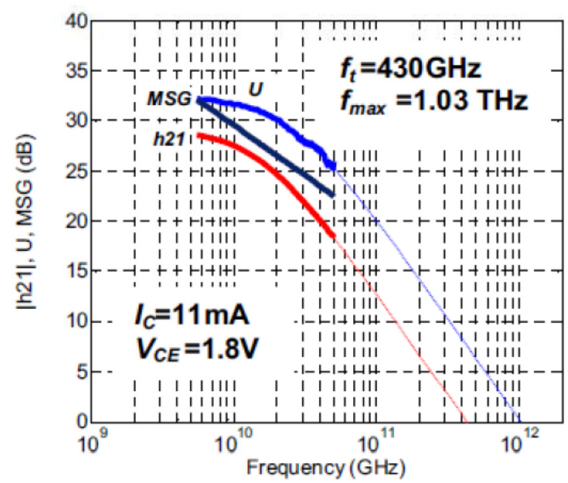
HEMT: f_{max} = 1.2 THz (NGC)





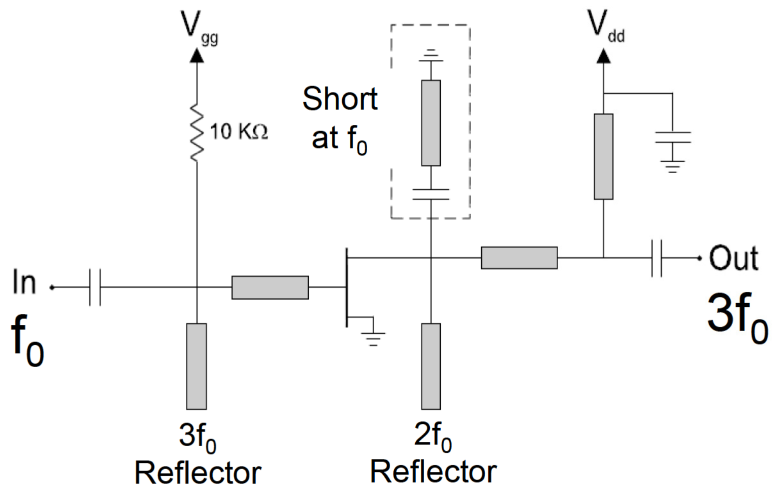
HBT: f_{max} = 1 THz (Teledyne)

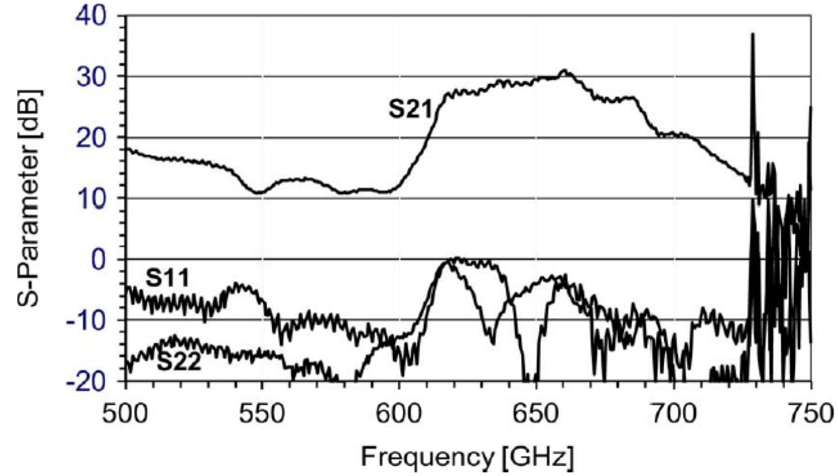


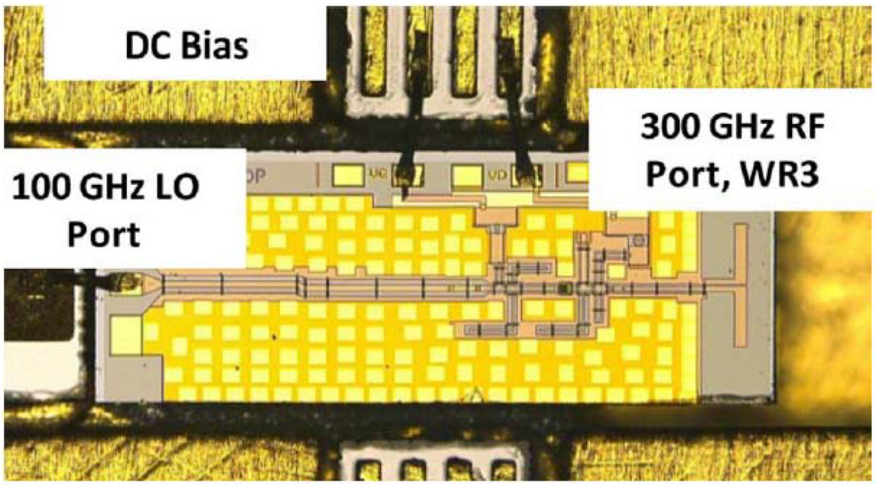


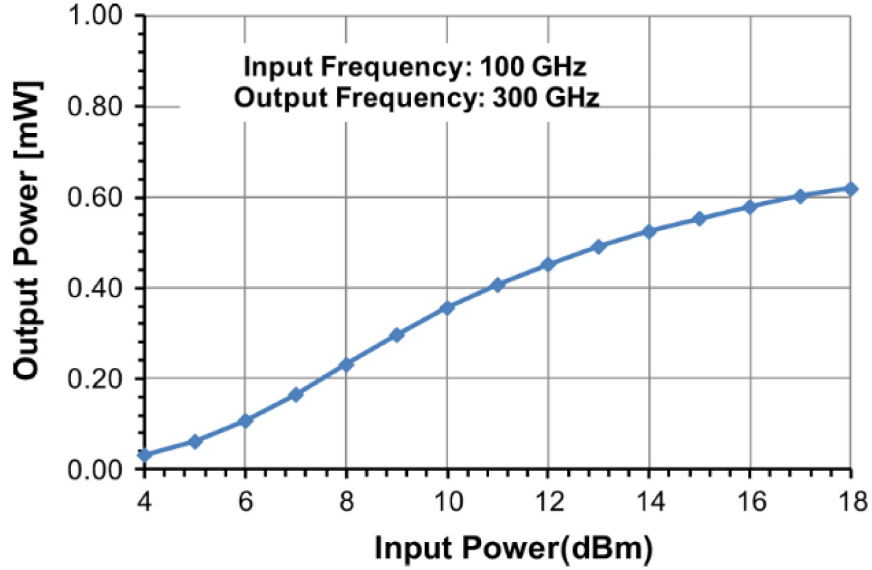
Ref: R. Lai et al., IEDM 2007 / M. Urtega et al., IPRM 2011

HEMT Based Sources





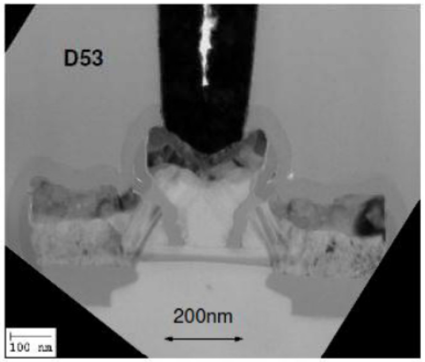


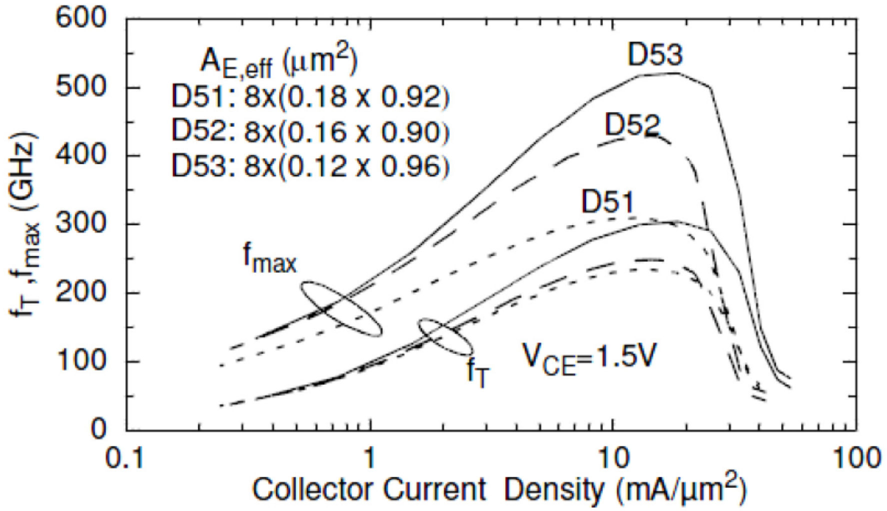


Ref: W. R. Deal, IEEE Trans. THz Sc. Tech., vol. 1, no. 1, pp. 25-32, Sept. 2011

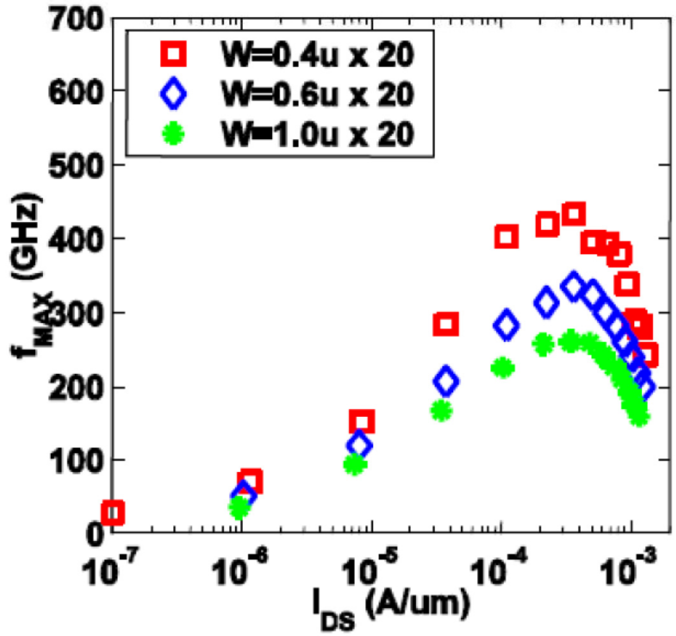
Silicon Based Technologies

SiGe HBT: f_{max} = 500 GHz (IHP)





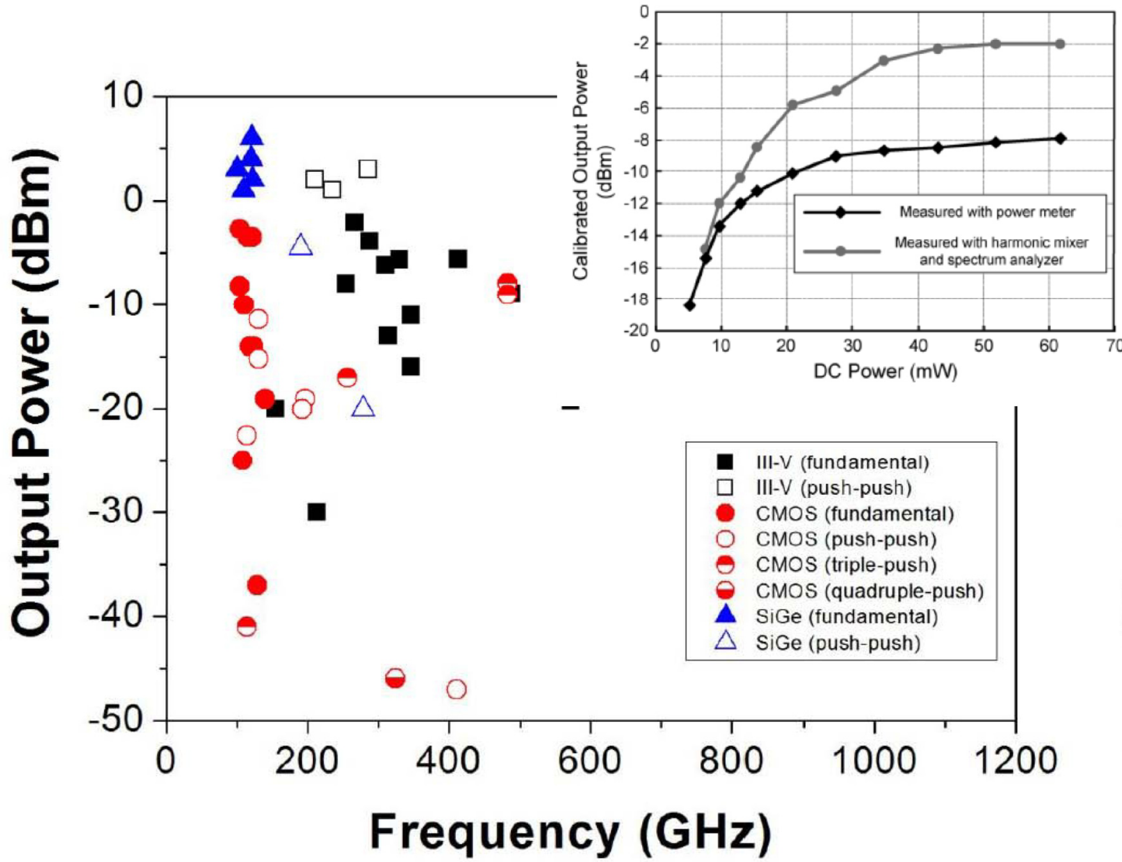
CMOS: f_{max} = 430 GHz (IBM)

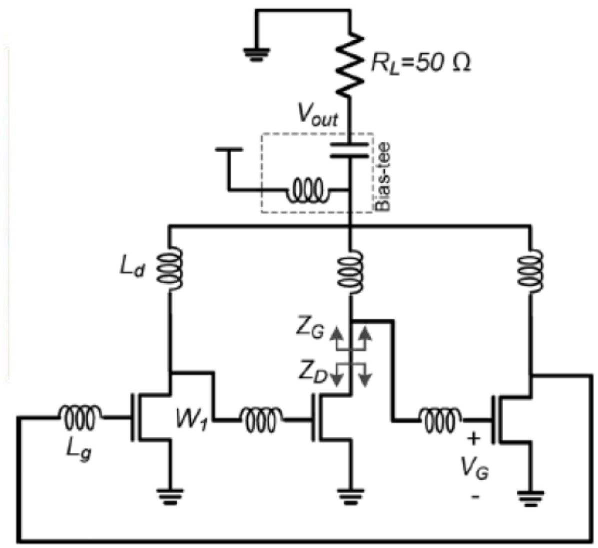


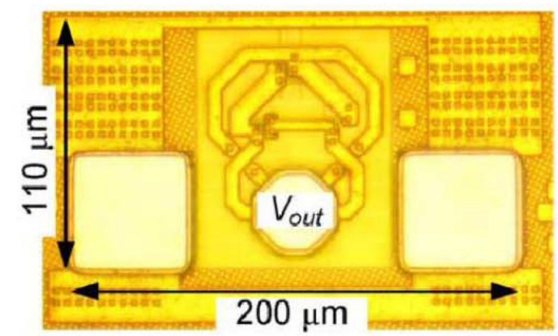
Ref: B. Heinemann et al IEDM 2010 / J-O Plouchart et al CSICS 2011

Silicon Based Sources

- Output power vs. Frequency







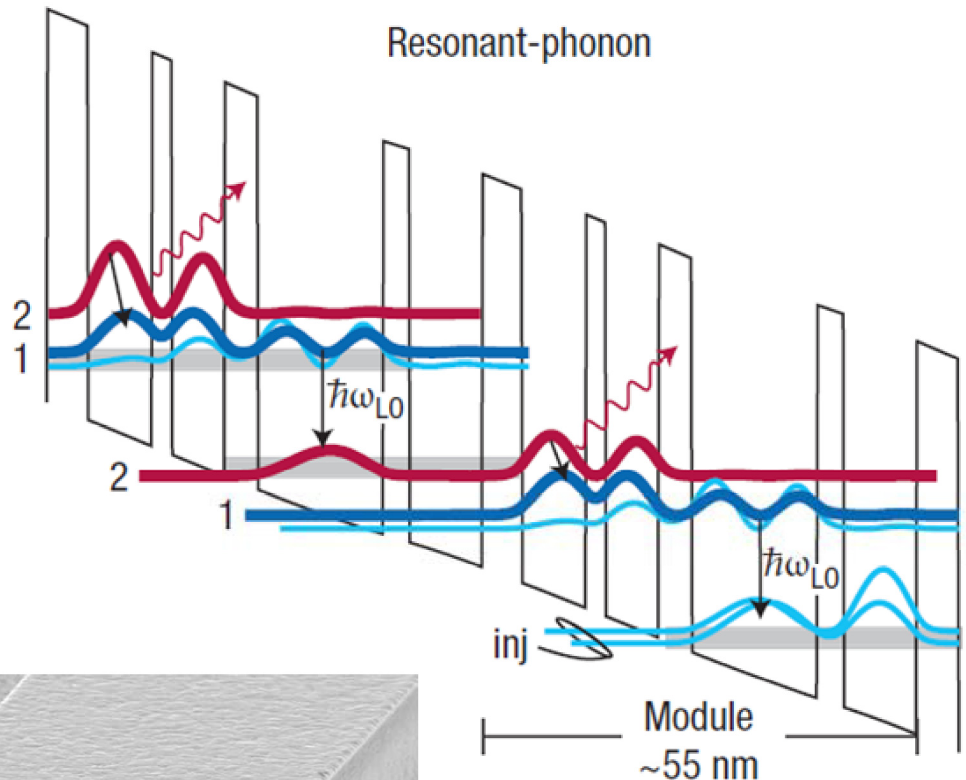
65 nm CMOS

-8 dBm @482 GHz

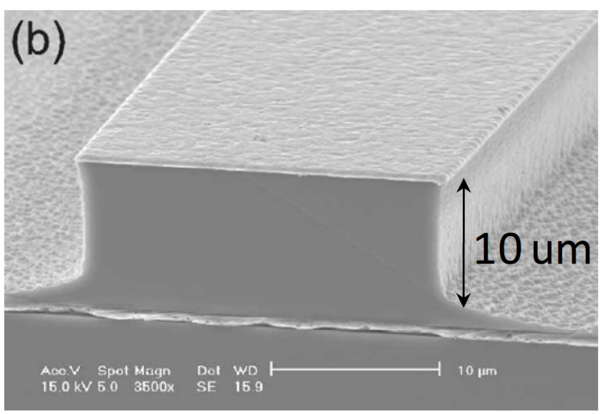
DC Power: 61 mW

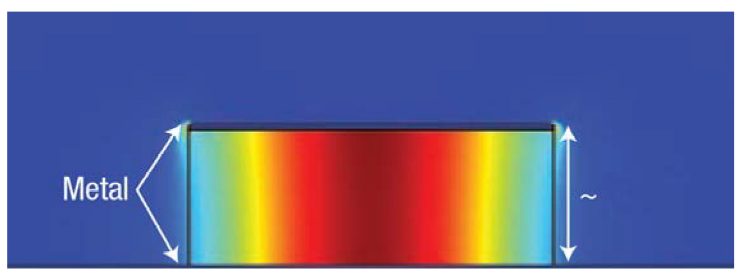
Ref: Momeni et al JSSC 2011 / Seo et al JSSC 2011

Quantum Cascade Lasers



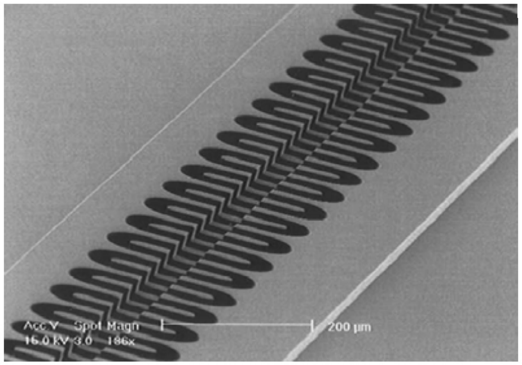
- Needs cryogenic operation
- Poor output beam quality
- Poor coupling efficiency
- Phase locking
- Narrow band

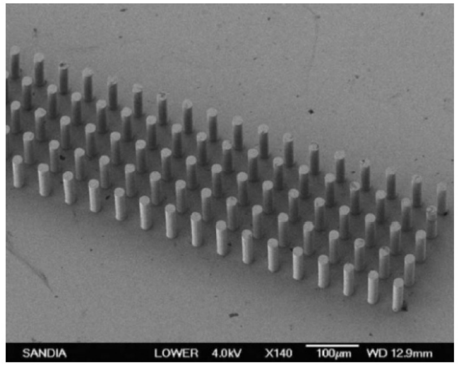


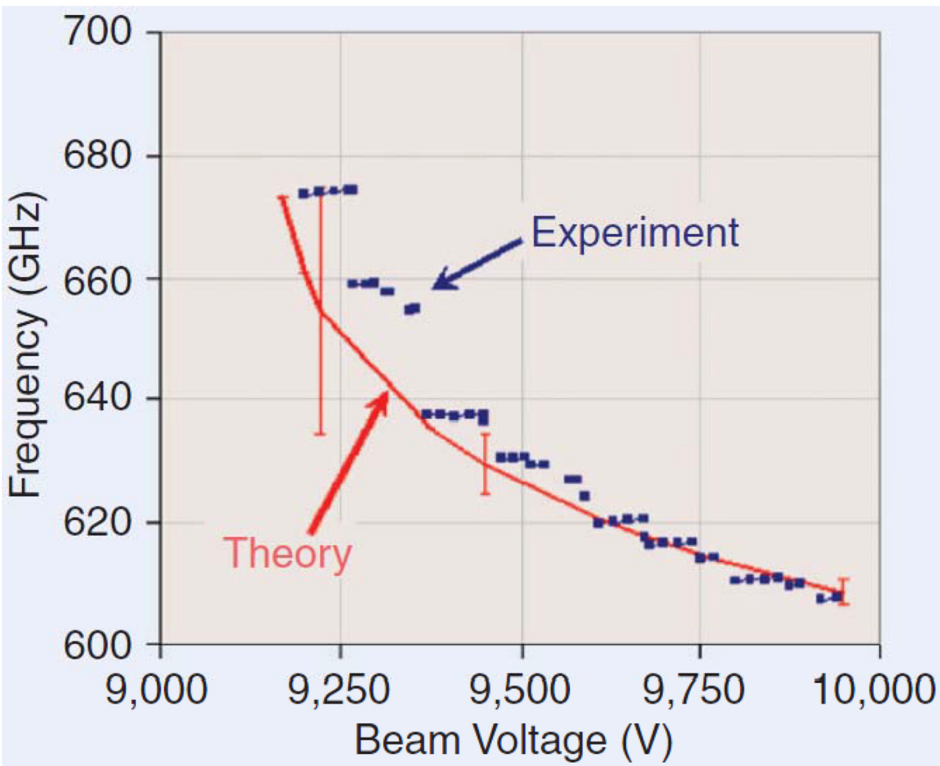


Ref: B. S. Williams, Nature Photonics, vol. 1, pp. 517–525, Sept. 2007.

Vacuum Electronic Devices





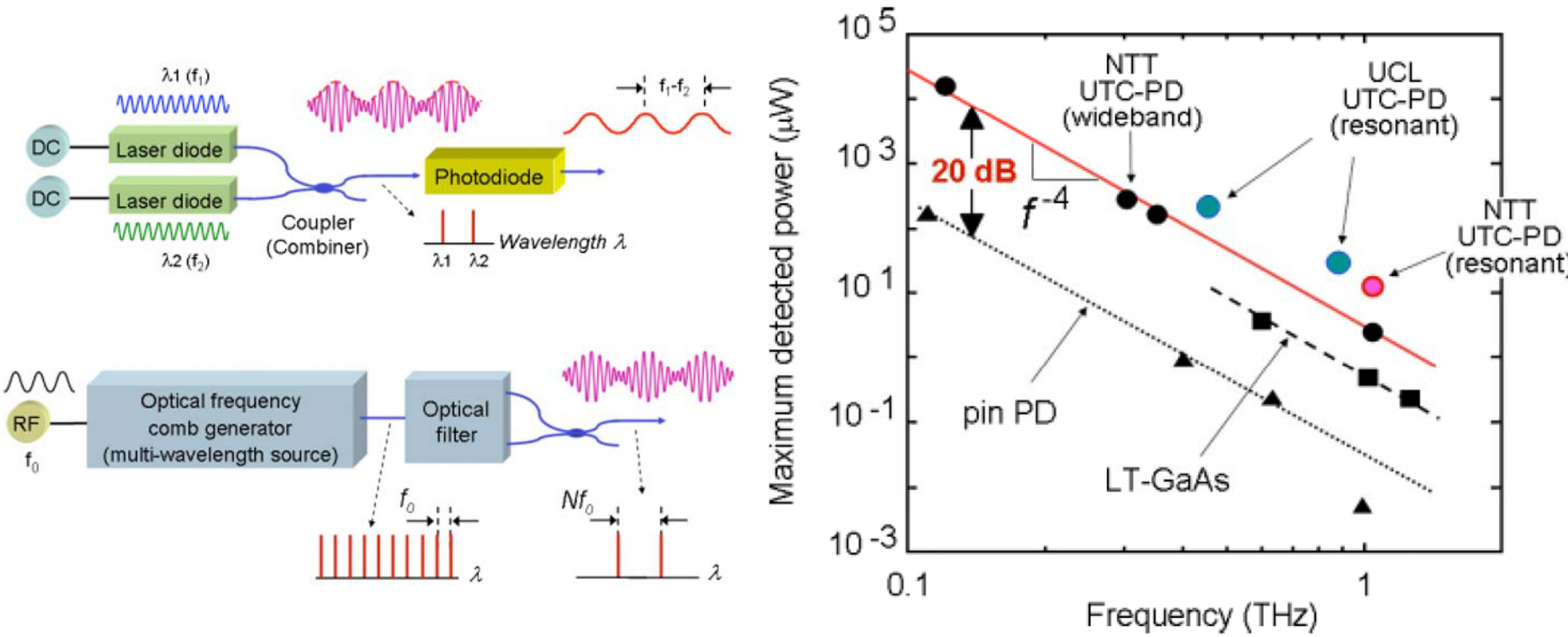


- Emission from bunched electrons moving in strong magnetic fields.
- Backward wave oscillators (BWOs), travelling wave tubes (TWTs).
- They are bulky
- Need high voltage operation
- Poor beam profile.

Recently, folded-waveguide (FWG) regenerative oscillator circuits have been successfully designed between 600–675 GHz with RF power levels over 50 mW at duty cycles up to 3%.

Ref:
- J. Tucek, K. Kreischer et al., Intl. Vacuum Electronics Conf., Monterey, 2008.
- R. L. Ives, IEEE Trans. Plasma Sc., vol. 32, no. 3, pp. 1277–1291, Jun. 2004.
- J. Tucek et al., Infrared mm and THz Waves, Rome 2010.

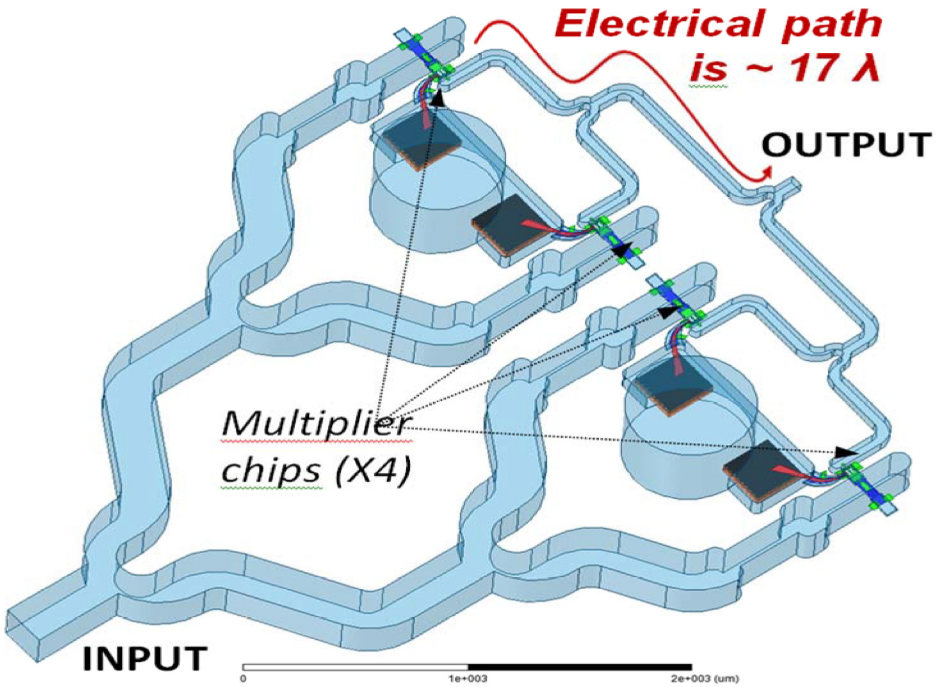
Photo Mixers



- Down-conversion of an optical signal to the terahertz band
- UTC-photodiode based photomixers produce the highest power
- LTG-GasAs based devices work at higher frequencies

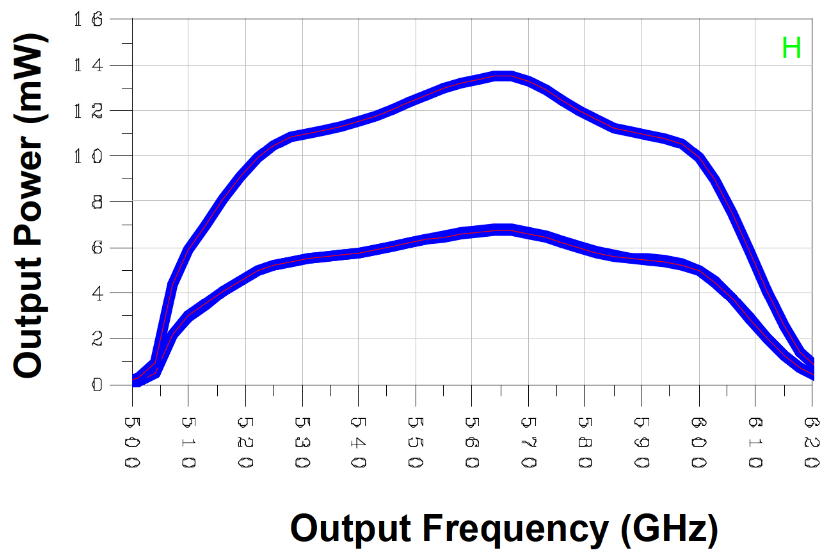
Ref: T. Nagatsuma, et al., Laser & Photon. Rev., vol. 3, no. 1–2, pp. 123–137, 2009.

Future Direction



Waveguide Power Combining

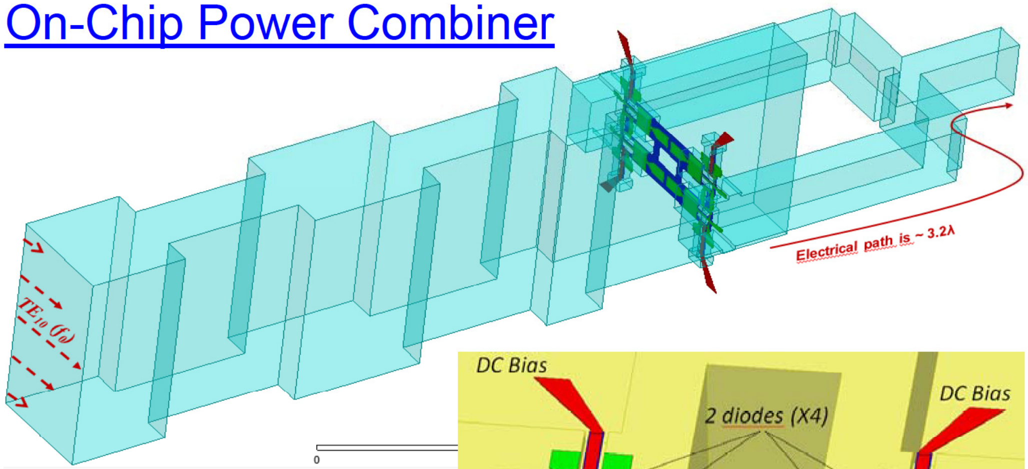
- Almost 4-times output power
- For higher frequencies, waveguide loss is a concern
- Devices need manual alignment

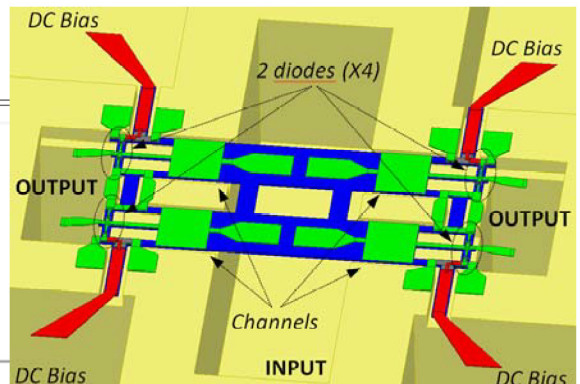


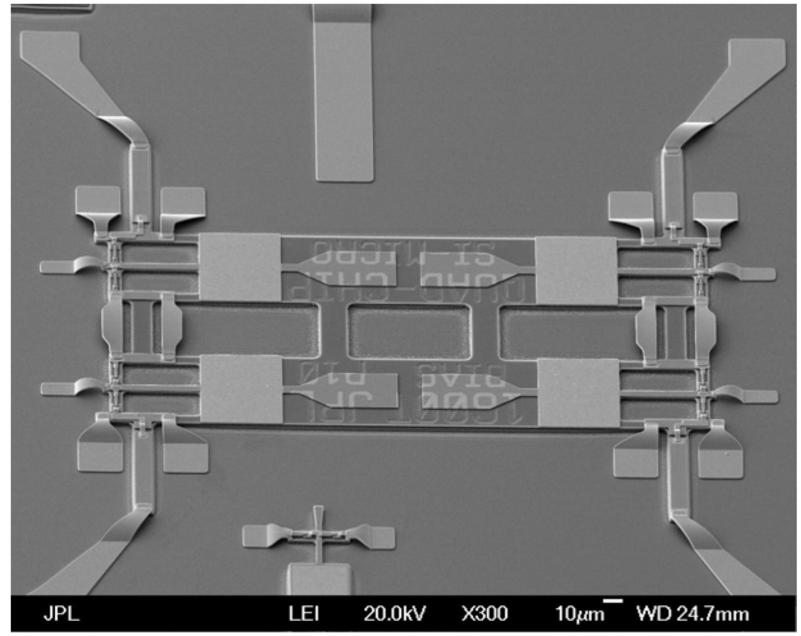
Ref: J. Siles, et al., Intl. Space THz Tech. Symp., Tokyo, Japan, April 2012.

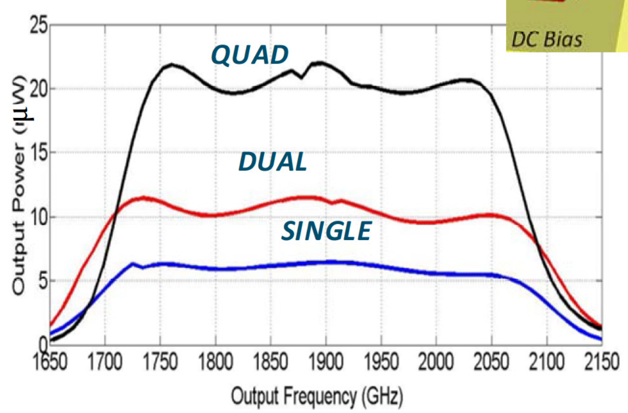
Future Direction

On-Chip Power Combiner

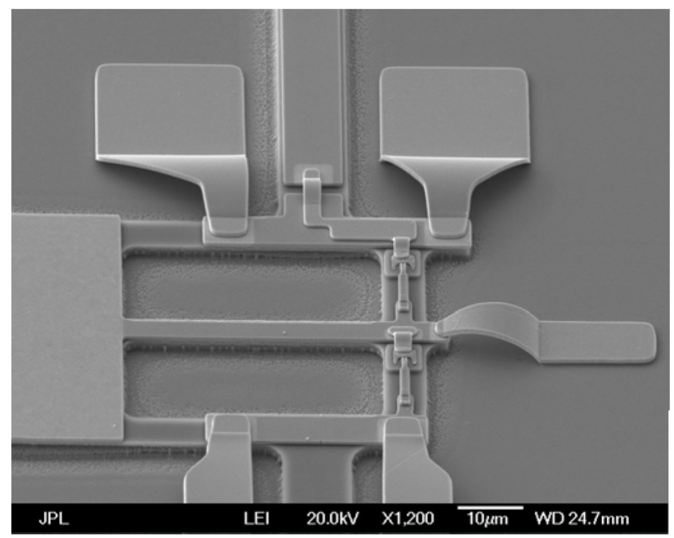








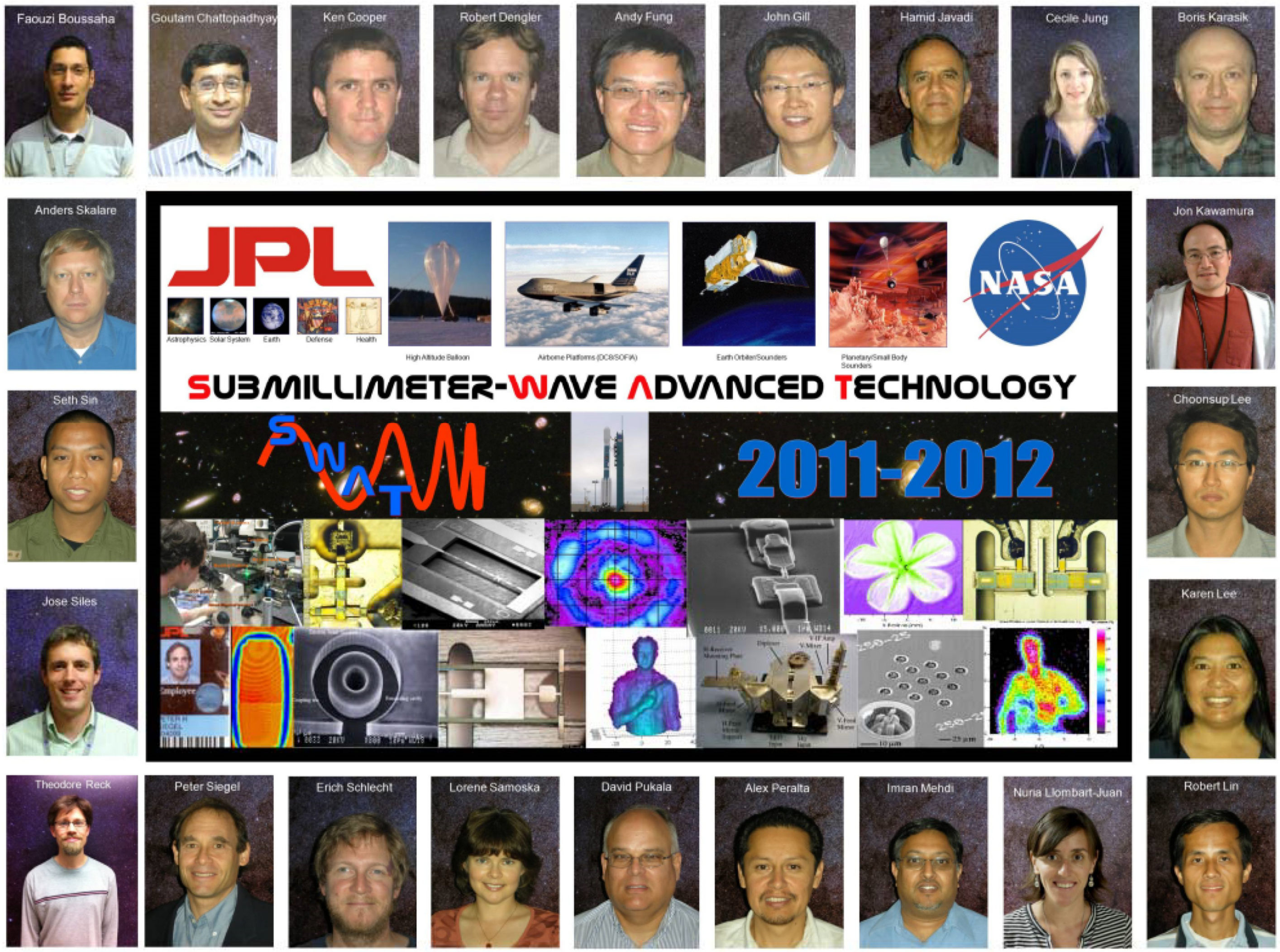
Ref: J. Siles, et al., Intl. Space THz Tech. Symp., Tokyo, Japan, April 2012.



Summary

- Schottky diode based frequency multipliers are most common
- Output power of 2 mW at 1 THz
- QCLs, VEDs, and photomixers are making good progress
- Phase lock and frequency stability is important
- The key is to have higher power at higher frequencies
- On-chip power combining is a promising path forward.

Acknowledgement



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